DC surface flashover characteristics of ZnO/EP composites at room temperature and 77K

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1. Introduction

Epoxy (EP) resin based nano-composites are widely used as insulating materials in high voltage direct current (HVDC) high temperature superconducting (HTS) power cable. The cable termination operating at a temperature range from room temperature to 77 K is exposed to high electrical field which can cause surface flashover. In the present work, the DC surface flashover characteristics of ZnO/EP nano-composites was studied at both room temperature and liquid nitrogen temperature.

2. Experiment

2.1 Preparation of the nanocomposites

The surface of ZnO nano-particles was modified using KH-560 silane coupling agent. The samples were made by dispersing ZnO nano-particles into EP resin with weight (wt) percentages of 0%, 1%, 3%, 6% and 10%, respectively.

2.2 Tests of the surface flashover voltage

The experimental setup consisted mainly of a cooling system and a DC high voltage power system.

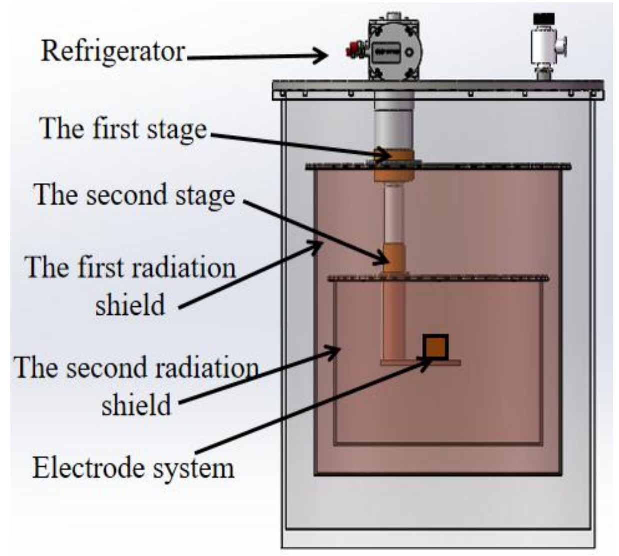

Figure 1. The cooling system.

The cooling system was sealed in a cryostat cooled by a GM refrigerator, including the external chamber, two radiation shields connected with the first and second stages, respectively, as shown in figure 1.

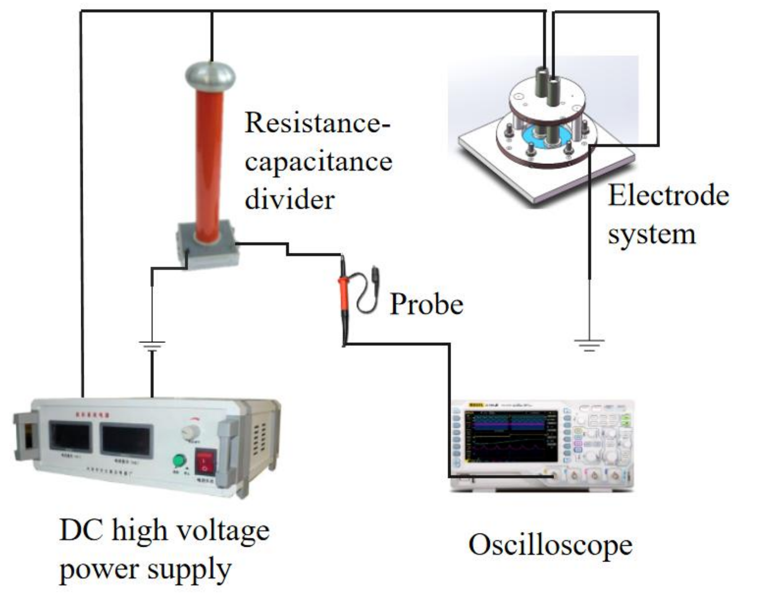

Figure 3. The DC high voltage power system system.

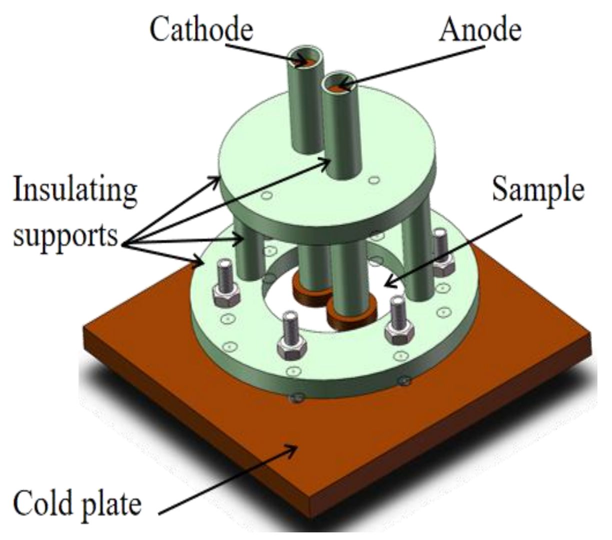

Figure 2. The electron system.

The structure of the electrode system encapsulated in the second radiation shield chamber was shown in figure 2. The cold plate and two electrodes were marked in bronze. The insulating supports which fixed the sample and the electrodes were marked in shallow green. The sample was marked in white.

High voltage was supplied by a DC high voltage power supply. The oscilloscope, as well as the resistance-capacitance divider and the probe were uesd to measure the surface flashover voltage, as shown in figure 3.

3. Results

The test results were described by the Weibull distribution, as shown in figure 4 and figure 5, respectively.

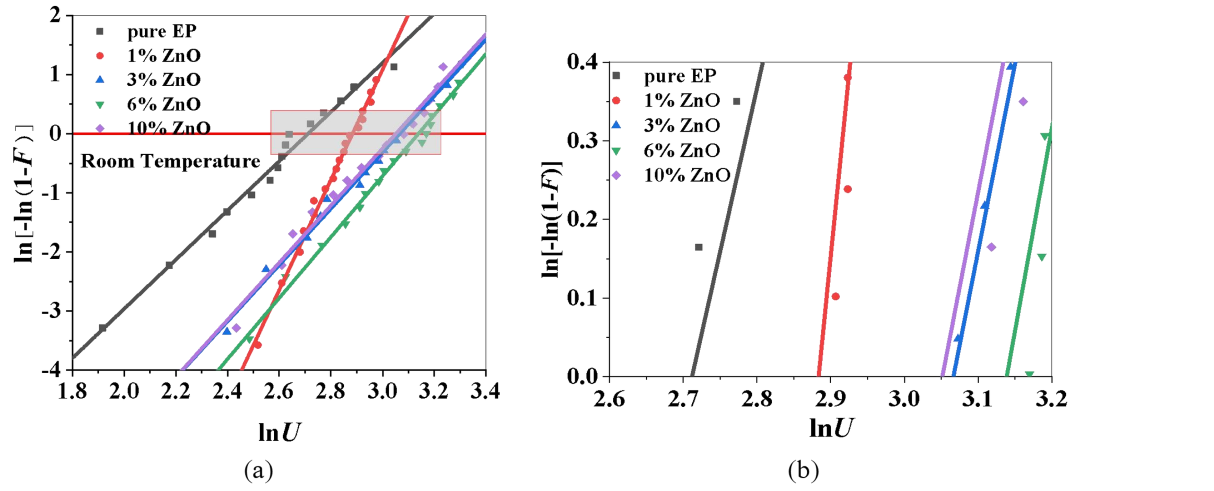

Figure 4. The surface flashover test results at room temperature.

At room temperature, Compared with the pure EP, the surface flashover voltage of the sample containing 1wt% ZnO increased obviously. When 3wt%, 6wt% and 10wt% ZnO were added, the surface flashover voltages of the samples had little difference, but were higher than that of the sample containing 1wt% ZnO.

At 77 K, the surface flashover voltages of each sample manifested little difference. For the samples containing 0wt%, 1wt%, 3wt%, and 10wt% ZnO, the surface flashover voltages increased with the increase of the content of ZnO. The flashover voltage of the sample containing 6wt% ZnO was slightly lower than that of the samples containing 3wt% ZnO.

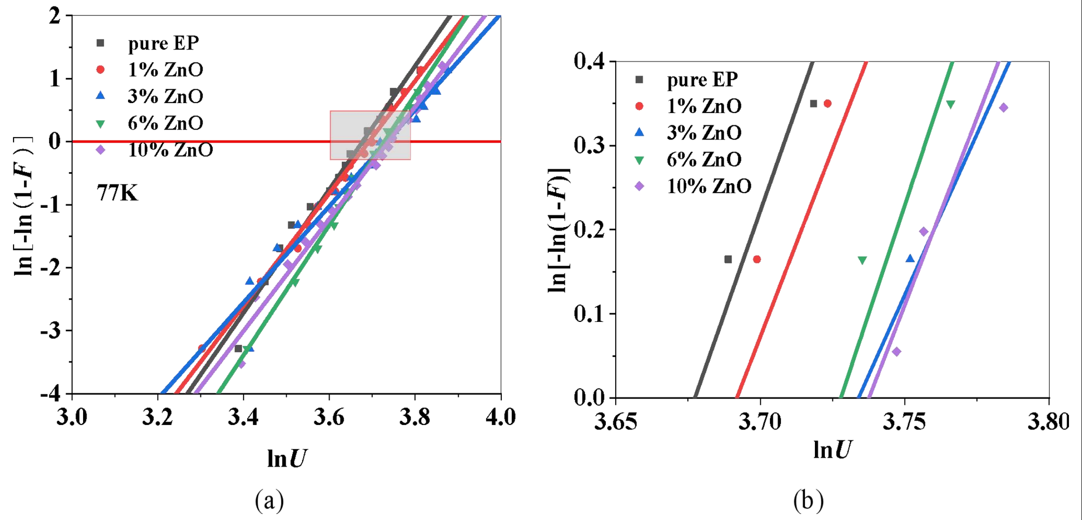

Figure 5. The surface flashover test results at 77 K.

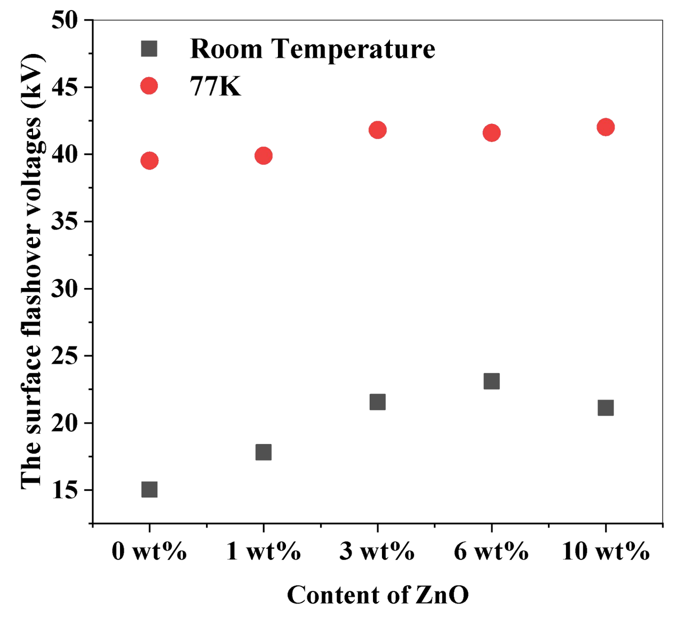

Figure 6. The voltages for which the failure probability was 0.632.

The surface flashover voltages for which the failure probability was 0.632 were calculated and plotted in figure 6. It showed that the surface flashover voltages at 77K were higher than those at room temperature for the samples with the same content of ZnO.

4. Discussion

To study the effect of space charges and trap levels on the surface flashover characteristics, Thermally Stimulated Direct Current (TSDC) were measured. The trapped charges *Q* and the activation energy *E* were calculated and were shown in table 1. The TSDC curves were shown in figure 7.

Table 1. The trapped charge Q and the activation energy E.

	Q/nC	E_I /eV	E_{II} /eV
Pure EP	13.35	—	0.28
1%ZnO	3.51	—	0.56
3%ZnO	0.22	—	0.69
6%ZnO	3.48	0.22	0.89
10%ZnO	10.22	0.65	0.89

At room temperature, it was assumed that the pure EP contained more space charges and the trap level was shallow, hence the surface flashover voltage was the smallest. For the samples containing 1wt%, 3wt% and 6wt% ZnO, the trap levels were deeper, thus the surface flashover voltages increased. For the sample containing 10wt% ZnO, although the trap level was deeper than those of the other samples, the space charges were much more than that of the other samples (except the pure EP), either. Hence the surface flashover voltage was close to those of the samples containing 3wt% and 6wt% ZnO.

At 77 K, it was considered that due to the decrease of the amount of the initial electrons emitted from the triple-junction, the amount of the secondary electrons decreased. Although the trap levels of ZnO/EP composites were deeper, the effect of the levels of traps was not as significant as that of the temperature. Therefore, with the increase of the content of ZnO, the surface flashover voltages tended to increase, but the increase was slight.

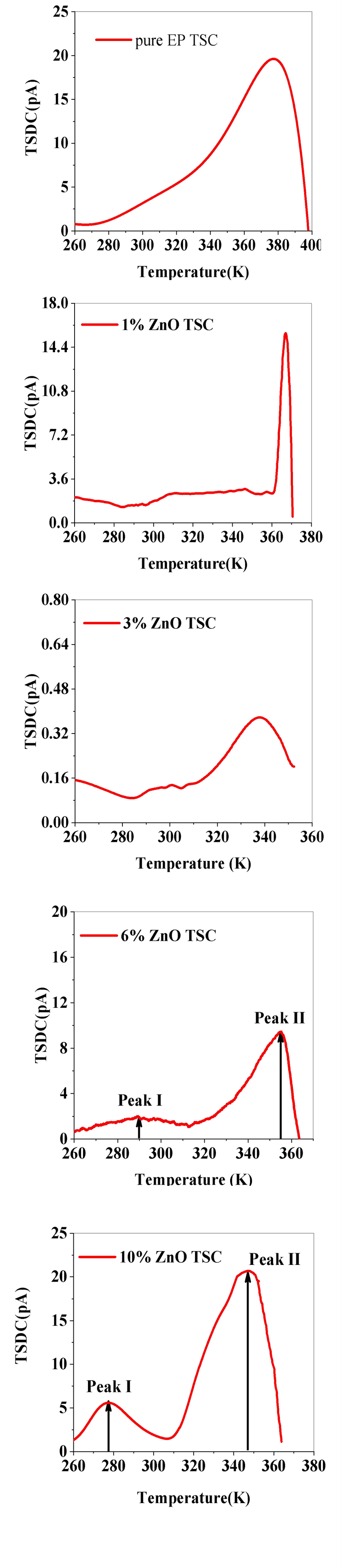

Figure 7. TSDC of each sample

5. Conclusion

Compared with pure EP, composites that doped with ZnO nanoparticles manifested higher surface flashover voltages at both room temperature and 77 K, and the increase of the surface flashover voltages was more observably at room temperature. It was assumed that ZnO nanoparticles introduced more deep traps thus increased the surface flashover voltage. For the composites with the same ZnO content, the surface flashover voltages at 77 K were significantly higher than that at room temperature due to the difference between the amount of the electrons.